CHARACTERIZING THE EFFECT OF SHOCK ON ISOTOPIC AGES II: Mg-SUITE TROCTOLITE MAJOR ELEMENTS.

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Introduction: Two troctolites from the lunar magnesium suite (Mg-suite), 76335 and 76535, have ^{147}Sm-^{143}Nd and ^{87}Rb-^{87}Sr ages that do not indicate the same age for their respective sample. In the case of 76335, the ^{147}Sm-^{143}Nd age is 4278 ± 60 Ma [1], but the ^{87}Rb-^{87}Sr data does not reveal an isochron [2]. For 76535, the ^{147}Sm-^{143}Nd age is significantly younger (4260 ± 60 Ma [3]) than the ^{87}Rb-^{87}Sr age (4570 ± 70 Ma, $\lambda = 1.402\text{x}10^{-11}$ [4]). This study was designed to discover why the ^{147}Sm-^{143}Nd and ^{87}Rb-^{87}Sr ages did not match for each individual sample.

Observations: Sample 76335 is composed of anorthite ($An_{98}Ab_2$) and olivine (Fo_{88}), with minor orthopyroxene ($En_{87}Fs_{12}Wo_1$) and various trace phases (including chromite, baddeleyite, zirkelite, metal, and merrillite). Microprobe analysis indicates that 76335 Fe-Ni-Co metal has Ni and Co abundances indicative of pristine rocks, supporting the conclusions of [5] and the status of 76335 as a monomict breccia.

Troctolite 76535 is unlike 76335 in most physical features, but is very much like 76335 in geochemistry. Sample 76535 is a coarse-grained annealed rock complete with 120° triple grain junctions [6], while 76335 is a cataclastite. Investigations are ongoing to determine if 76335 is part of the 76535 parent pluton, but with at least one subsequent cataclastic event that 76535 did not experience. There are a few points of evidence that would imply a shared origin. First, their geochemical pairing [7]. Second, their almost identical bulk trace element pattern [8, 9]. Third, the overlap of 76335 and 76535 in ^{147}Sm-^{143}Nd age versus ε_{Nd}^{143} space [1]. Lastly, remnant 120° triple grain junctions and small linear inclusions of pyroxene [10] in the anorthite of cataclastized 76335 match those observed 76535. These shared features may indicate that the samples originated from the same parent pluton. Thus, the near identical ^{147}Sm-^{143}Nd ages may indicate the true age of both troctolites, while the subsequent cataclastic event experienced only by 76335 may have disturbed the ^{87}Rb-^{87}Sr isotopic systematics sufficiently to prevent an isochron.

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References: [1] Edmunson J. et al. 2007. Abstract #1962. 38th Lunar & Planetary Science Conference. [2] Edmunson J. 2007. Abstract #4069. Workshop on the Chronology of Meteorites & the Early Solar System. [3] Lugmair G. W. et al. 1976. 7th Lunar & Planetary Science Conference. pp. 2009-2033. [4] Papanastassiou D. A. and Wasserburg G. J. 1976. 7th Lunar & Planetary Science Conference. pp. 2035-2054. [5] Ryder G. et al. 1980. 11th Lunar & Planetary Science Conference. pp. 471-479. [6] Gooley R. et al. 1974. *Geochimica et Cosmochimica Acta* 38: 1329-1339. [7] James O. 1980. 11th Lunar & Planetary Science Conference. pp. 365-393. [8] Haskin L. A. et al. 1974. 5th Lunar Science Conference. pp. 1213-1225. [9] Warren P. H. and Wasson J. T. 1978. 9th Lunar & Planetary Science Conference. pp. 185-217. [10] Nord G. L. Jr. 1976. 7th Lunar Science Conference. pp. 1875-1888.

Characterizing the Effect of Shock on Isotopic Ages II
Mg-suite Troctolite Major Elements

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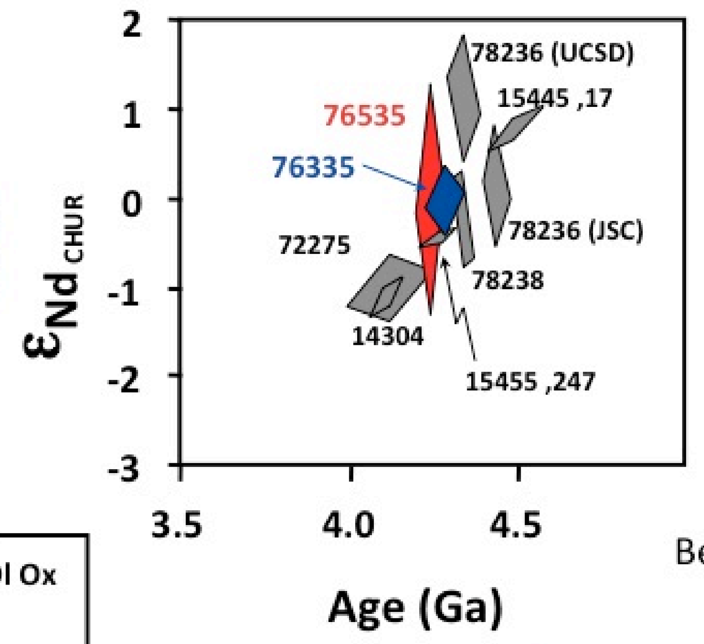
76335

Photomicrograph of troctolite 76335,61. Note extreme cataclasis.

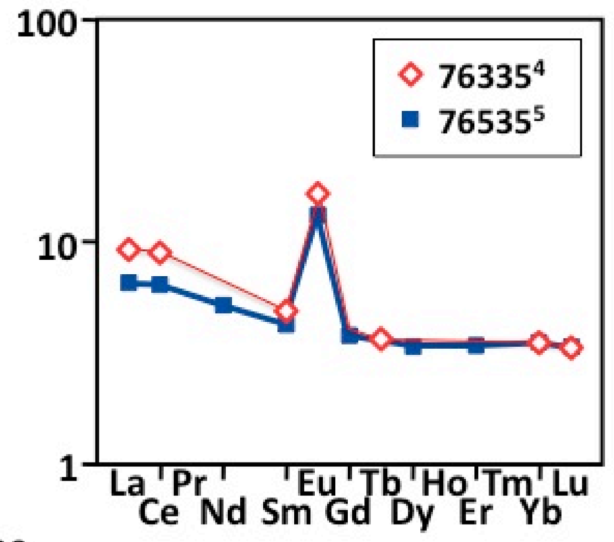


Troctolites 76335 and 76535 have nearly identical ^{147}Sm-^{143}Nd ages and systematics, but the ^{87}Rb-^{87}Sr systematics do not match the ^{147}Sm-^{143}Nd systematics or each other. Below, we attempt to answer why.

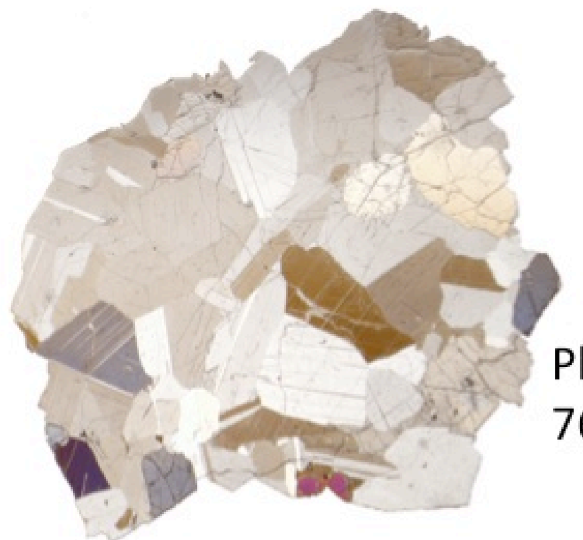
←Diagram shows magnesium-suite samples in age vs. ε_{Nd} space. Note the overlap of 76335 and 76535 [3].

Rare earth element (REE) plot comparing bulk rock→ compositions of 76335 and 76535 [4,5].

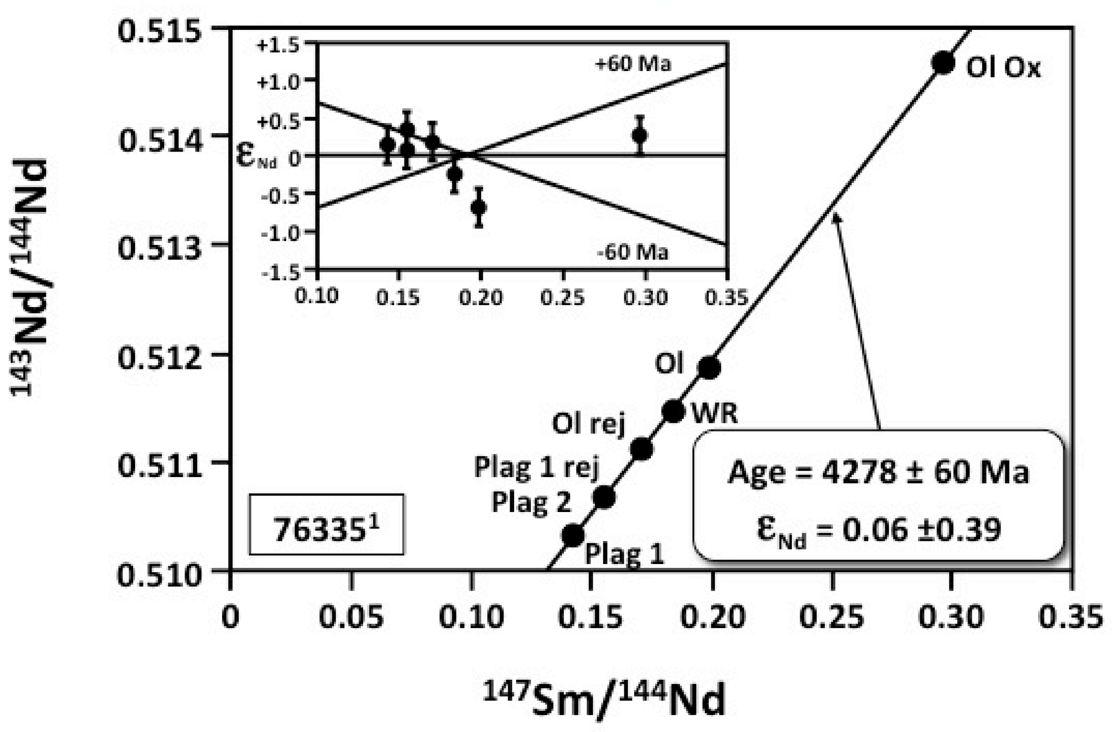
Below: similarities between 76335 and 76535 in: (top) pyroxene inclusions in plagioclase [6], (bottom) remnant textures.↓

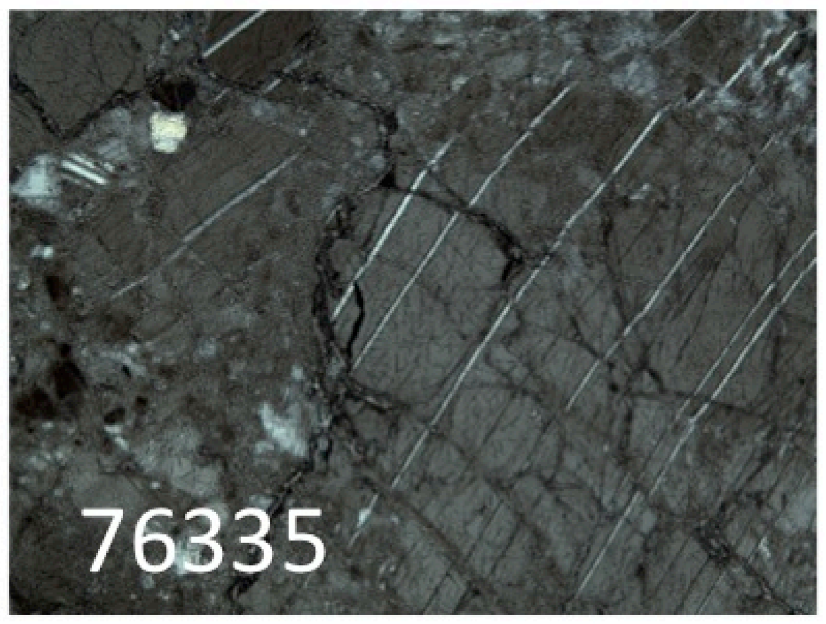


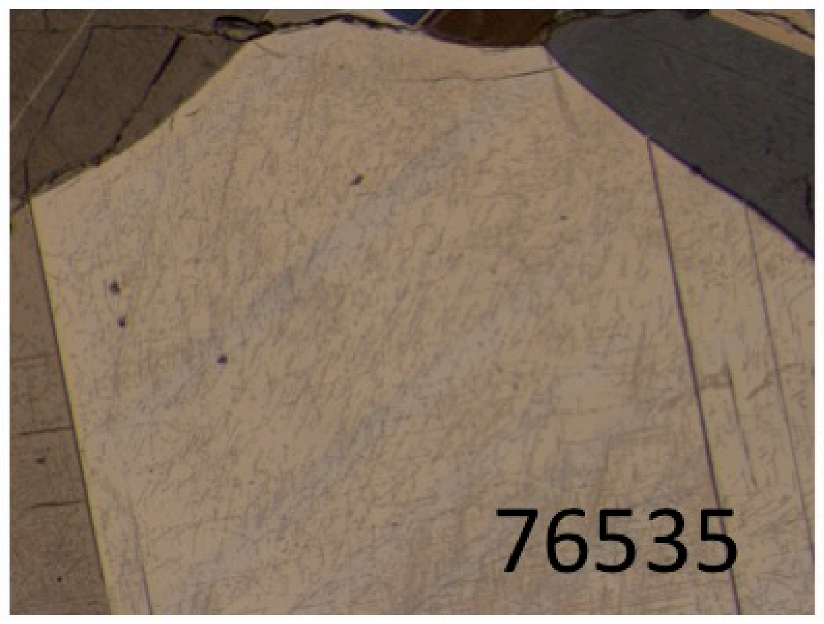
76535

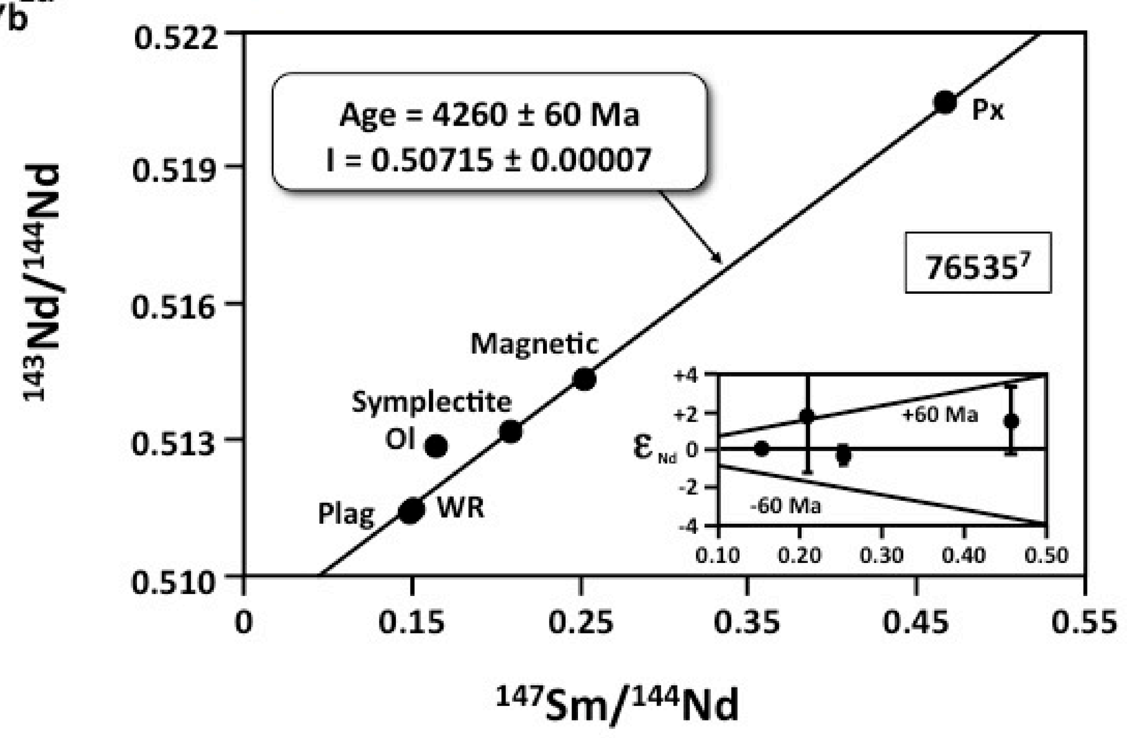


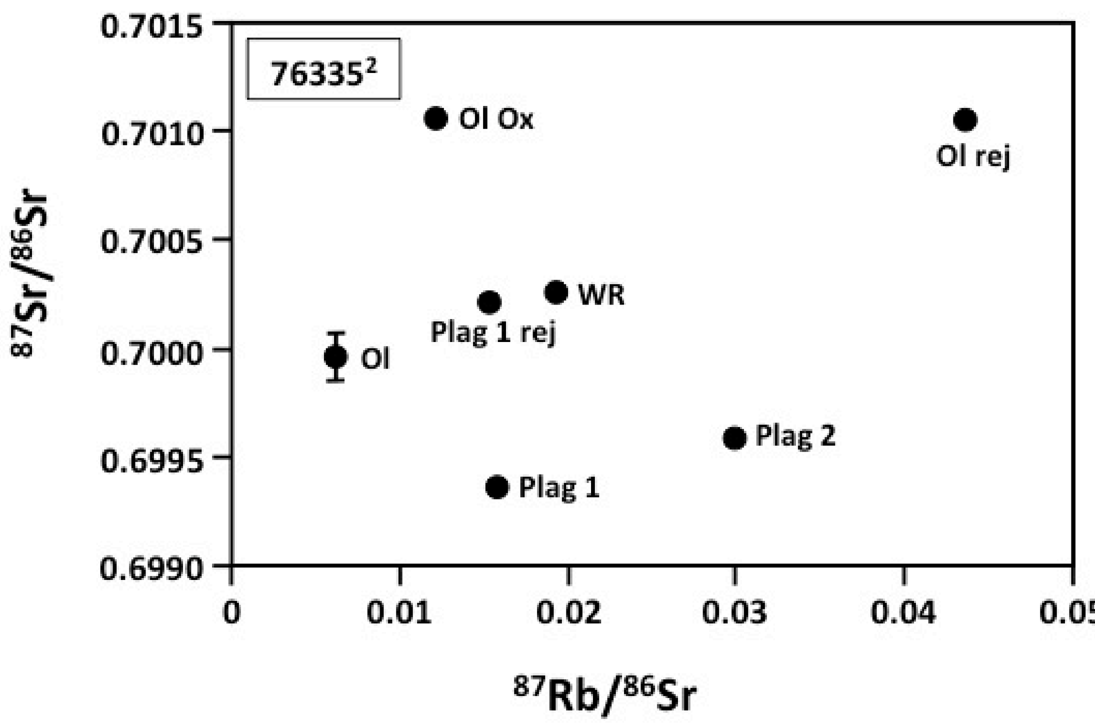
Photomicrograph of 76535,152.

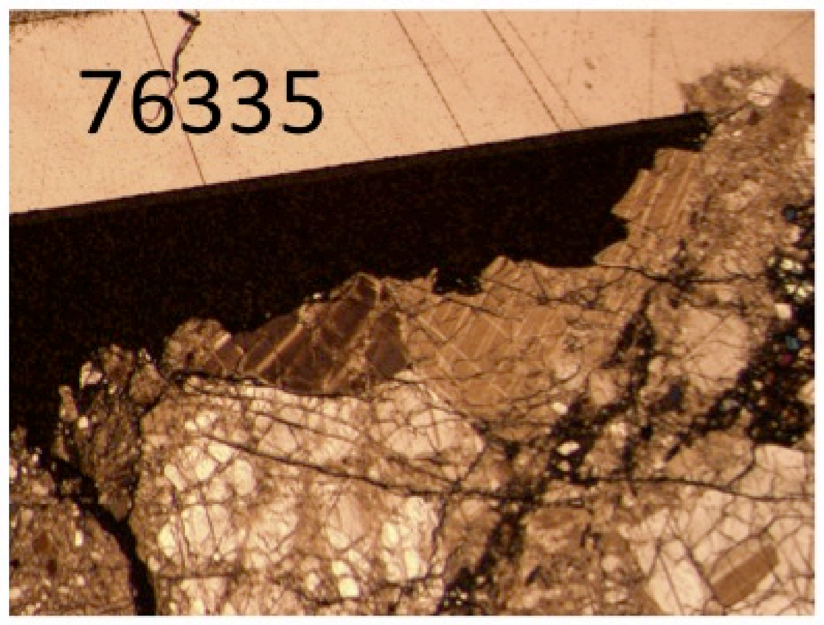


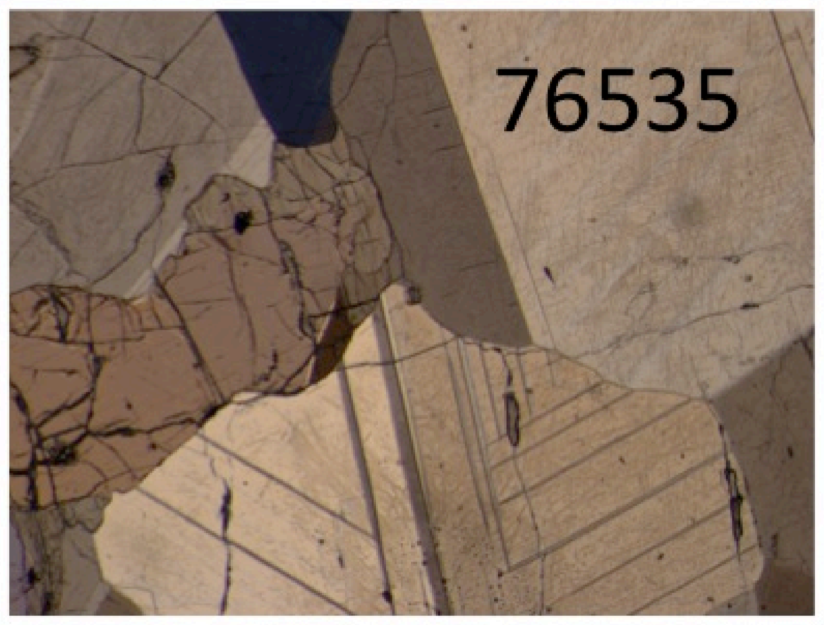


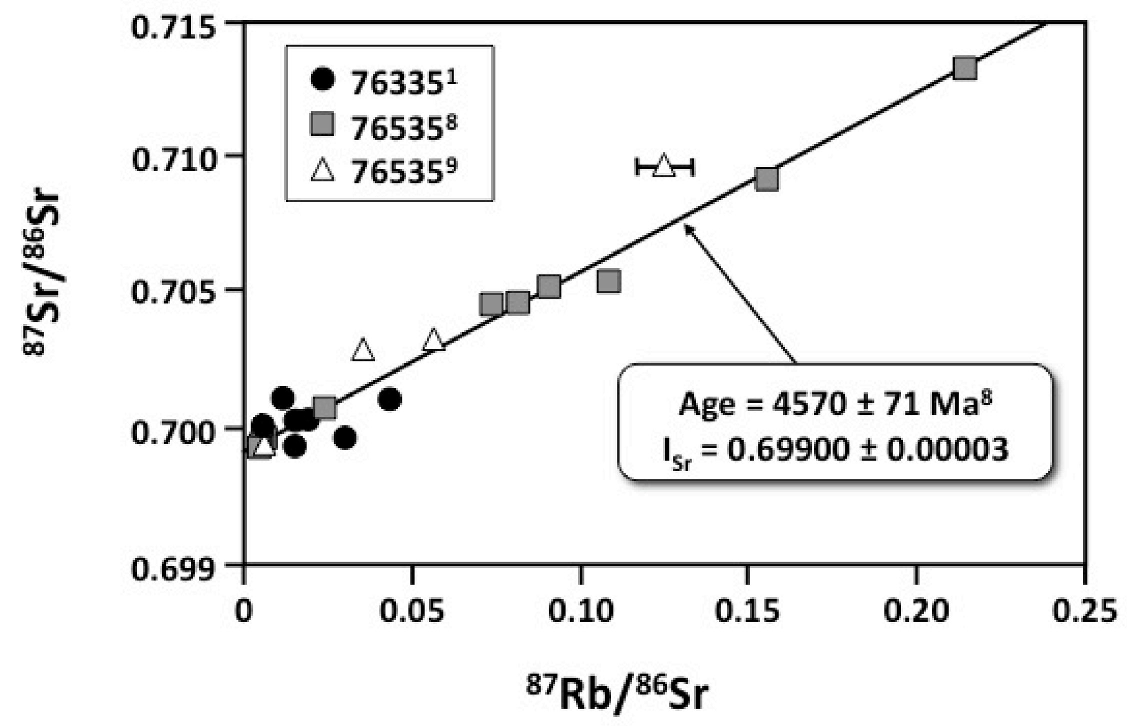








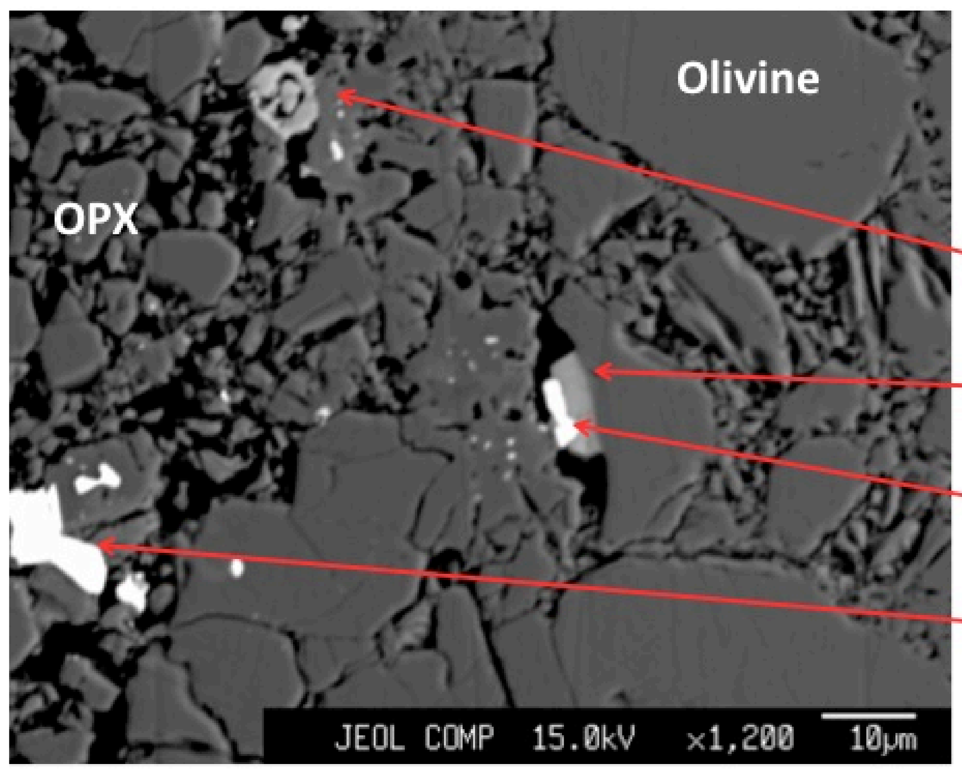




76335 Yttrium Silicate

A yttrium silicate with the approximate composition $Y_2Si_2O_7$ was observed in 76335. This silicate contains high concentrations (weight percent) of REEs (see figure at right) and other radioactive elements. The composition $Y_2Si_2O_7$ is the formula for the mineral yttrialite. The yttrium silicate in 76335 was not verified as a structural match for yttrialite because an electron backscatter diffraction (EBSD) pattern was not obtainable. Multiple efforts by Chi Ma to obtain an EBSD patterns from the mineral only proved that the structure was amorphous, likely due to the significant radiation damage the mineral experienced during its long life on the Moon (Chi Ma, personal comm. May 21, 2009).

A REE pattern was produced using detailed analysis using the microprobe at Washington University by Paul Carpenter and Ryan Zeigler. The yttrium silicate in 76335 has a strikingly similar REE pattern to yttrialite thought to be a result of breakdown of zircon [10] (see figure at right). Accessory phases baddeleyite and zirkelite are also present in 76335 and 76535.



Some trace phases in troctolite 76335:

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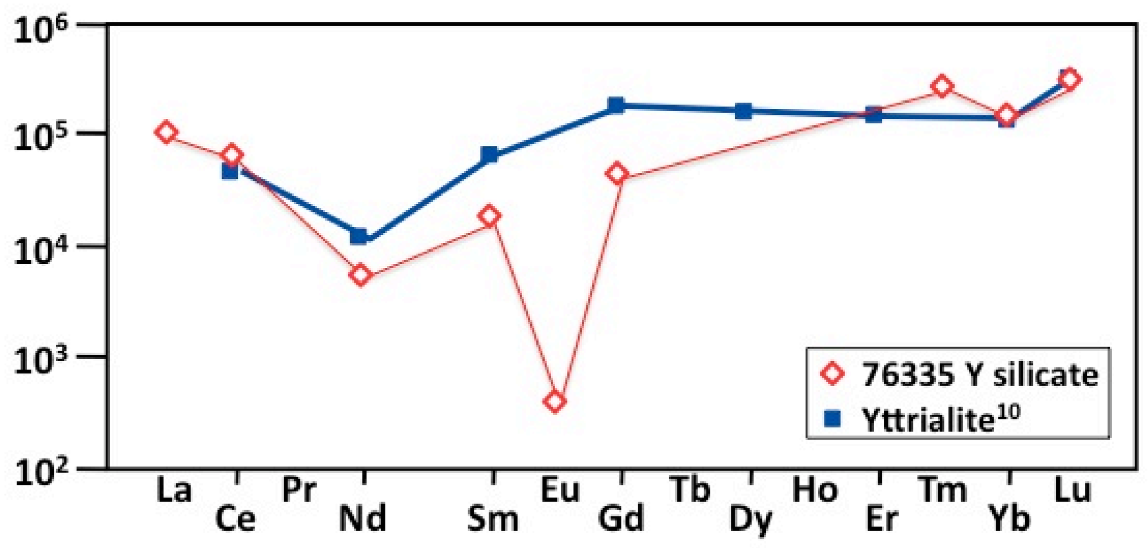
References: [1] Edmunson J. et al. (2007) 38th Lunar and Planetary Science Conference, #1962. [2] Unpublished data referenced in Edmunson J. (2007) Workshop on the Chronology of Meteorites and the Early Solar System, #4069. [3] Edmunson J. and Borg L. E. (2006) Workshop on Early Planetary Differentiation, #4034. [4] Haskin L. A. et al. (1974) 5th Lunar Science Conference, 1213-1225. [5] Warren P. H. and Wasson J. T. (1978) Proceedings of the 9th Lunar and Planetary Science Conference, 185-217. [6] Nord G. L. Jr. (1976) Proceedings of the 7th Lunar Science Conference, 1875-1888. [7] Lugmair G. W. et al. (1976) Proceedings of the 7th Lunar Science Conference, 2009-2033. [8] Papanastassiou D. A. and Wasserburg G. J. (1976) Proceedings of the 7th Lunar Science Conference, 2035-2054. [9] Bogard D. D. et al. (1975) Earth and Planetary Science Letters 26, 69-80. [10] Spandler C. et al. (2004) American Mineralogist 89, 1795-1806. [11] Hoskin P. W. O. and Black L. P. (2000) Journal of Metamorphic Geology 18, 423-439. [12] Ganguly J. and Tirone M. (2001) Meteoritics and Planetary Science 36, 167-175. [13] McCallum I. S. et al. (2006) Geochimica et Cosmochimica Acta 70, 6068-6078. [14] Nyquist L. E. et al. (1991) 22nd Lunar and Planetary Science Conference, 985-986. [15] Premo W. R. and Tatsumoto M. (1992) Proceedings of the 22nd Lunar and Planetary Science Conference, 381-397. [16] Snyder G. A. and Taylor L. A. (1994) 25th Lunar and Planetary Science Conference, 1309-1310.



Both yttrialite [10] and the yttrium silicate found in 76335 may be enriched in LREEs due to the preferential expulsion of LREEs from zircon during breakdown [11]. Thermally activated anhydrous recrystallization via particle and defect volume diffusion [11] may have ultimately produced the yttrium silicate in 76335.

Implications to Geochronology

The breakdown of zircon via particle and defect volume diffusion implies that 76335 experienced temperatures of approximately 750°C [11] long enough to create an entirely new mineral. This temperature is higher than the ^{147}Sm-^{143}Nd closure temperature [12] and the temperature for cation ordering [13], and thus likely occurred during a long-term cooling history in which the textures noted in the above figures were imparted to both 76335 and 76535. Therefore, the parent pluton of 76335 and 76535 existed prior to the age recorded by the ^{147}Sm-^{143}Nd isotopic system, and a yttrium silicate phase should be found in 76535.

Comments can also be made on the ^{87}Rb-^{87}Sr isotopic systematics of these two samples based on the comparisons above. Rubidium loss was measured in a sample experimentally heated to 800°C [14] and long-term heating of the parent pluton may be responsible for producing an older ^{87}Rb-^{87}Sr "pseudo-isochron" for 76535 [15]. In fact, Rb loss can be easily seen in two of the olivine mineral fractions from 76335 (ol and ol ox). Given the observed severity of Rb loss, and the resulting relatively low $^{87}Sr/^{86}Sr$ ratios, it is likely that the Rb loss event occurred very early in the history of the sample. Volatility of Rb during cataclasis/meteoritic bombardment likely promoted Rb loss in 76335 over 76535 (e.g., [16]).